A NEW PARADIGM TO EVALUATE THE CLEAVAGE ENERGY OF BRITTLE MATERIALS

Dov Sherman, School of Mechanical Engineering, Tel-Aviv University, Israel
dovsherman@tauex.tau.ac.il
Merna Shaheen-Mualim, School of Mechanical Engineering, Tel-Aviv University, Israel

Key Words: Cleavage energy; Brittle materials; Energy gradient; Dynamic bond breaking mechanisms; Kinks.

Crack initiation in brittle materials is usually dictated by the energy required to create two new surfaces. This energy is known as Griffith barrier and equals twice the free and relaxed surface energy, $2g_s$. This value is usually taken as the cleavage energy for crack propagation as well. We investigated, experimentally, the fundamentals of cracks dynamics in brittle crystals, with emphasis on the cleavage energy at initiation and during propagation. Silicon crystal served as a model material, where two of its low energy cleavage systems (LECSs) were examined. During experiments, the gradient of the quasi-static energy release rate (ERR) for unit length of crack advance, $dG_0/da \equiv Q$ (in units of J/m^2/mm), was revealed as a new critical variable not discussed before, with a critical influence on the material property [1,3].

When loaded by low Q (< 0.5 J/m^2/mm), in air, a complex and diverse stress corrosion cracking (SCC) behavior was revealed; the cleavage energy strongly depends on Q, the environment and crystallographic structure. We further show that at Q > 0.7 J/m^2/mm, the SCC mechanisms vanish for both LECSs, and the cracks initiate and propagate at cleavage energy higher than that in vacuum, or the Griffith barrier of $2g_s$, twice the free surface energy of the cleavage plane. The highest values obtained in the experiments for the (110)[1 $\bar{1}$ 0] and (111)[11 $\bar{2}$] LECSs, were 1.47 and 2.14 times $2g_s$ J/m^2, respectively (see Fig. 1). Surprisingly, the cleavage energy for initiation and propagation remain constant during the event of fracture for a prescribed Q, meaning, it is not crack speed dependent. Moreover, we show that all the variables participating dynamic cleavage are linearly dependent on Q, which provides the evidences that the ERR gradient is the controlling variable governs cracks dynamics. Report of cleavage energy should be accompanied by the value of Q. The variety of Q may explain the large scatter of the cleavage energy of silicon existing in the literature.

We suggest that the causality of the above fundamental behavior is laying on the way crack initiate and propagate at the atomistic scale, i.e., the bond breaking mechanisms in form of planar kinks with complex energy consumption mechanisms.

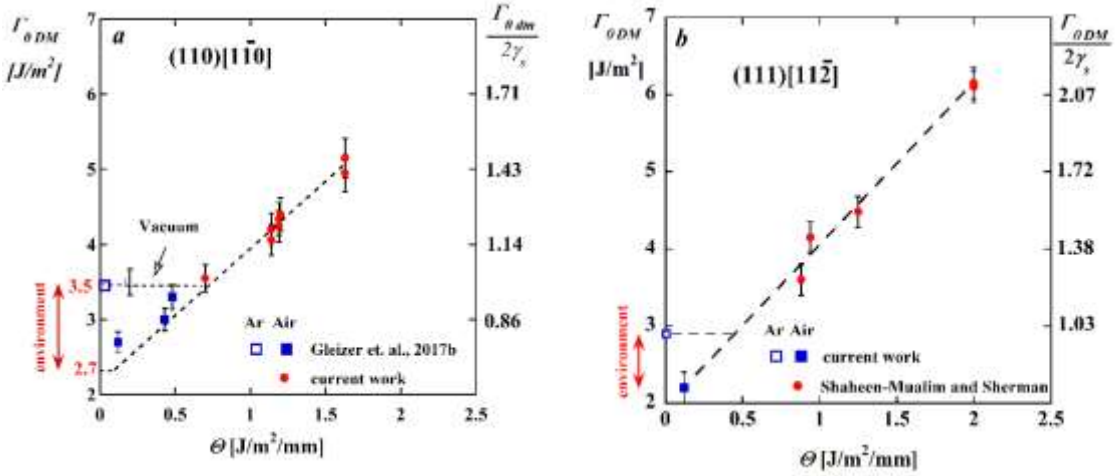

Fig. 1. The cleavage energy at initiation, $G_{0\,DM}$, as a function of Q and environment for the two LECSs of silicon crystal, a (110)[1 $\bar{1}$ 0] and b, the (111)[11 $\bar{2}$].

1. M. Shaheen-Mualim and D. Sherman. Int. Journal of Engineering Science 129,111-128 (2018).
2. M. Shaheen-Mualim, A. Gleizer, and D. Sherman. Accepted. Int. Journal of Fracture (2019).
3. A. Gleizer and D. Sherman. Int. J. Fracture 187, 1-14 (2014).